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Original Research Article

Substitution of ramie (*Boehmeria nivea*) for alfalfa in improving the carcass and meat quality of Liuyang Black goats

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A B S T R A C T

Ramie (*Boehmeria nivea*) is noted for the production of a large biomass that has a high protein content and is rich in antioxidants. It may thus serve as a high-quality forage material to replace alfalfa and improve the meat quality of farmed animals. In this study, we evaluated the carcass characteristics and meat quality of goats when 0, 35%, 75%, and 100% of dietary alfalfa was replaced with ramie. Crude protein content (linear, $P < 0.0001$) and key muscle color values at 24 h after slaughter decreased with increasing ramie levels. The content of most individual amino acids, non-essential amino acids (NEAA), total amino acids (TAA), branched chain amino acids (BCAA), functional amino acids (FAA), and flavor amino acids (DAA) decreased ($P < 0.05$) with increasing dietary ramie. The diet in which 35% of alfalfa was replaced with ramie yielded meat with the highest amino acid content, whereas the fatty acid profile was unaffected by the inclusion of ramie. These results indicate that ramie could be used as a potential dietary forage resource for goats, and that substituting 35% of alfalfa with ramie, which is equivalent to 126 g/kg DM content, would be optimal in terms of goat meat quality.

1. Introduction

Alfalfa is an excellent forage source widely used to feed ruminants, particularly dairy cows. Although localized production of high-quality forage is an efficient means of reducing feeding costs, forage sources of high quality and yield for ruminants are often seasonally insufficient within China, which imported 1.398 million tonnes of alfalfa for this purpose in 2018 (Shen et al., 2019). Accordingly, a secure supply of forage materials is important to support animal husbandry and food production in China.

Ramie (*Boehmeria nivea*), a perennial plant in the family Urticaceae, is well adapted to the hot and humid climate of South China, with a high biomass yield and an annual domestic output of up to 3.19×10^6 kg/hm^2 (Zeng et al., 2009). Its leaves are characterized by high protein and essential amino acid (EAA) content (Spoladore et al., 1984; Lu and Zhang, 1996; Contò et al., 2011). Ramie has been applied as an alternative feedstuff for monogastric animals such as rabbits (Gabbi et al., 2004), rats (Duarte et al., 1997), and pigs (Li et al., 2018a). In rabbits, the average daily gain can be improved by 8.95% when 7.5% of dietary alfalfa is replaced with ramie (Toledo et al., 2008). However, in Boer goats, increasing dietary ramie results in a decrease in daily gain (Wei et al., 2018). The

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methods used for processing ramie could influence the digestibility of its nutrients by goats and thereby, the quality of goat meat (Zhang et al., 2019). Alternatively, there may simply be an upper limit to nutrient availability as a higher proportion of dietary alfalfa is replaced by ramie, which will constrain goat growth performance (Tang et al., 2019).

Improving the quality of animal products is a key focus of animal nutrition studies, and various methods are used to achieve this goal. A high antioxidative capacity is known to be beneficial with respect to meat quality and shelf life (Ma et al., 2010; Lu et al., 2014; Zhang et al., 2015), and in this regard, ramie is rich in antioxidants, including polyphenols and flavonoids (Kim, 2010). In rats, the serum lipid profile (Lee et al., 2014) and lipid metabolism (Lee et al., 2011) can be improved by providing these animals with ramie leaf extract or dietary ramie leaf inclusion. In finishing pigs, carcass traits and muscle chemical composition can also be improved by the inclusion of up to 9% ramie leaf powder in the diet (Li et al., 2018a). However, less information is currently available on the effects of ramie substitution in ruminants. In this study, we investigated the effects of dietary ramie inclusion in goats and estimated the appropriate proportions of ramie as a dietary replacement for alfalfa.

2. Materials and methods

The trial reported herein was conducted at the experimental farm of the Institute of Subtropical Agriculture, the Chinese Academy of Sciences. The protocol and experimental procedures were approved by the Animal Care Committee of the Institute of Subtropical Agriculture (Approval, 20,160,112).

2.1. Ramie

Ramie (*B. nivea* 'Zhongzhu No.1') was planted in an experimental field at the Institute of Bast Fiber Crops, Chinese Academy of Agricultural Sciences (Changsha, Hunan, China). Whole ramie plants were harvested upon reaching a height of 1.2 m, cut into 3 to 4 cm lengths, and sun dried. Chemical composition (DM basis) of the ramie was: crude protein 173 g/kg, neutral detergent fiber 621 g/kg, acid detergent fiber 449 g/kg, Ca 36.2 g/kg, P 2.75 g/kg, and ash 138 g/kg (Tang et al., 2019).

2.2. Animals and experimental design

Thirty-two male Liuyang Black goats (6 to 8 months of age) were treated for parasites with 0.2 mg/kg ivermectin, 10 mg/kg albendazole, and 20 mg/kg praziquantel and allowed to adapt to the environment over a 2 wk period. The goats were then divided into 2 blocks of 16 individuals according to body weight: block B1 with an average body weight of 16.7 ± 1.72 kg and block B2 with an average body weight of 26.6 ± 2.95 kg. Each block was randomly subdivided into 4 groups, each containing 4 goats. The groups were fed diets in which 0, 35%, 70%, or 100% of alfalfa had been replaced with ramie, which corresponded to an intake of approximately 0, 94.5, 189, and 270 g ramie per day. The ingredients and chemical composition of the diets (Table 1) and animal management were conducted as previously described (Tang et al., 2019). All goats were individually housed in stainless steel metabolic cages and provided free access to fresh water. The experiment lasted 45 d.

2.3. Sample collection and treatment

At the end of the experiment, all goats were fasted for 24 h and water was withheld for 12 h. The animals were weighed, and then electrically stunned and exsanguinated. Fresh carcass weights were recorded following flaying, decapitation, evisceration, and feet removal. A cross-section imprint from the right *longissimus dorsi* (LD) muscle at the junction of the final thoracic and first lumbar vertebrae was obtained using sulfuric acid paper. The area of the imprint was determined by planimetry and was considered to represent the loin-eye area. Samples of skeletal muscle tissue, namely the LD between the thirteenth rib and the 3rd and 4th lumbar vertebrae, as well as the entire *vastus lateralis* (VL) and *gluteus medius* (GM) muscles, were collected from the right side of the carcasses. Sinew and visible fat were removed from the muscles, and samples used to determine chemical composition were stored at −20 °C.

Table 1
Ingredients and nutrient composition and metabolizable energy of diets (g/kg, DM basis)[1].

Item	Alfalfa: Ramie			
	100:0	65:35	25:75	0:100
Ingredients				
Alfalfa	360	234	108	0
Ramie	0	126	252	360
Rice straw	240	240	240	240
Corn	100	180	245	280
Wheat bran	255	180	110	70
Fat powder	15	8	10	15
Calcium hydrophosphate	5	7	10	10
Salt	5	5	5	5
Mineral and vitamin premix [2]	20	20	20	20
Chemical composition				
ME, MJ/kg	8.54	8.58	8.62	8.75
CP	115	116	111	111
NDF	479	488	478	459
ADF	286	275	265	261
Ca	27.3	26	28.5	28.9
P	1.74	1.84	2.22	2.35
Ash	94.3	97.2	107	110.8

ME = metabolism energy; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; Ca = calcium; P = phosphorus.
[1] Data were obtained from Tang et al. (2019).
[2] Contents per kilogram: 5.88 g $FeSO_4 \cdot 7H_2O$, 2.33 g $CuSO_4 \cdot 5H_2O$, 11.96 g $MnSO_4 \cdot H_2O$, 8.29 g $ZnSO_4 \cdot H_2O$, 20 mg Na_2SeO_3, 50 mg KI, 35 mg $CoCl_2 \cdot 6H_2O$, 90,000 IU vitamin A, 17,000 IU vitamin D, and 17,500 IU vitamin E.

2.4. Meat quality measurements

For LD, VL, and GM muscles, pH was determined at 45 min and 24 h postmortem using a portable pH meter (pH-STAR; SFK-Technology, Copenhagen, Denmark). For drip loss determination, a fresh meat sample of 50 ± 2 g was placed in an inflated plastic bag, which was sealed and reweighed after 24 h storage at 4 °C (Zhong et al., 2009). Drip loss was expressed as the percentage of weight lost in proportion to the original weight. For meat color determinations, samples were cut and left at room temperature for 10 to 15 min to facilitate color development. Lightness (L^*), redness (a^*), and yellowness (b^*) were measured at 24 h postmortem using a handheld colorimeter (CR-410; Minolta Camera, Co., Osaka, Japan) calibrated against a standard white plate (8 mm aperture diameter, d/0 illumination system) (Li et al., 2018a).

2.5. Chemical quality analysis

The moisture content of fresh LD, VL, and GM samples was measured, and freeze-dried muscle samples were used to determine ash (920.153), fat (991.36), and crude protein (981.10) contents in accordance with standard analytical methods (AOAC, 2000).

2.6. Amino acid analysis

The amino acid content (985.28, AOAC, 2000) of LD muscle was measured using an ion-exchange amino acid analyzer (Hitachi L-8900; Tokyo, Japan) in accordance with AOAC (2000). Briefly, 0.1 g of ground LD muscle and 10 mL of 6 mol/L HCl were thoroughly mixed and hydrolyzed at 110 °C for 24 h. The hydrolysate thus obtained was transferred to a 100-mL volumetric flask and made up to volume with distilled water. One milliliter of the settled solution was filtered through a 0.45-μm membrane, and the filtered solution was diluted 10-fold for further analysis.

2.7. Fatty acid analysis

One gram of ground LD muscle was methylated following the procedure described by Sun et al. (2015). Methyl esters were separated and quantified using a gas chromatograph (7890A GC System; Agilent, Santa Clara, CA, USA) equipped with a flame-ionization detector and a 30-m fused silica capillary column with 0.25 mm inner diameter and 0.25 μm film thickness (ECONO-CAP EC100 FFAP; Alltech, Bridgewater, NJ, USA). The gas chromatography program was initiated at 140 °C, maintained at this temperature for 4 min, then raised in 5 °C/min increments to 230 °C and maintained at this temperature for 10 min. Injector and detector temperatures were 280 and 300 °C, respectively. Nitrogen was used as a carrier gas at a flow rate of 30 mL/min. Peak identification was based on fatty acid methyl esters standards. Fatty acid compositions were determined from the chromatogram peak areas and expressed as gram per 100 g of identified total fatty acid methyl esters.

2.8. Statistical analysis

SAS MIXED procedures (SAS Inst. Inc., Cary, NC, USA) were used to analyze carcass characteristics as well as amino acid and fatty acid compositions based on a completely randomized block design. The model included block, ramie treatment, and the interaction between block and ramie treatment as fixed effects. The model for chemical composition, muscle color, and drip loss analyses included block, ramie treatment, muscle, the interaction between block and ramie treatment, and the interaction between muscle and ramie treatment as fixed effects. Turkey's post hoc test was used for multiple comparisons. Individual animals were considered as random effects. Orthogonal polynomial contrasts were conducted to analyze the linear and quadratic effects of ramie proportion in the feed. IML procedures in SAS were used to correct the contrast coefficients of orthogonal polynomials. Differences were regarded as significant at $P < 0.05$, with $0.05 < P < 0.10$ being considered indicative of a tendency. Results are expressed as least square means.

3. Results

3.1. Slaughter characteristics

Carcass weight, dressing percentage, feed conversion rate, and loin-eye area were not significantly influenced ($P > 0.05$) by increasing dietary ramie proportion (Table 2).

3.2. Meat quality

The moisture content and drip loss of muscle after 24 h of storage were not affected by increasing proportion of dietary ramie ($P > 0.05$; Table 3). The content of crude protein (linear, $P < 0.0001$) and ash (linear, $P = 0.009$; quadratic, $P = 0.006$) decreased by 2.6% and 0.58%, respectively, when the proportion of alfalfa replaced with ramie was increased from 0 to 100%. Muscle fat content was significantly higher ($P = 0.006$) in goats fed a diet containing 75% ramie than in those consuming a diet containing 35% ramie (8.10% vs. 6.14%) or alfalfa alone (8.10% vs. 5.42%). Muscle color values at 24 h decreased with increasing proportion of dietary ramie (L^* linear, $P < 0.05$; b^* linear, $P = 0.003$). The value of b^* decreased by 1.44 when the proportion of ramie replacing alfalfa increased from 35% to 100%. At 45 min, the pH value of muscle also fell (from 6.68 to 6.50) in goats fed diets containing an increasing proportion of ramie (linear, $P < 0.05$).

The content of fat ($P = 0.003$) and ash ($P < 0.0001$), muscle color b^* at 24 h ($P = 0.0001$), and pH at 45 min ($P < 0.0001$) differed among the 3 muscles examined, with the highest fat and ash contents being observed in LD (LD vs. VL and GM, 7.98% vs. 6.37% and 5.75%) and GM (GM vs. LD and VL, 5.25% vs. 4.81% and 4.98%, respectively). The VL muscle had the lowest b^* value at 24 h (LD vs. VL and GM, 8.93 vs. 7.35 and 8.46), and the highest pH value at 45 min (VL vs. LD and GM, 6.73 vs. 6.49 and 6.44, respectively).

3.3. Amino acid concentrations

The content of Lys and His was not influenced by increasing dietary ramie ($P > 0.05$; Table 4), whereas the contents of Glu, Ala, Gly, and Arg, non-essential amino acids (NEAA), total amino acids (TAA), branched chain amino acids (BCAA), functional amino acids (FAA), and flavor amino acids (DAA) decreased linearly with an increase in the proportion of dietary ramie ($P < 0.05$). The highest values were measured in goats fed the diet containing 35% ramie. The ratio of EAA to NEAA increased linearly in response to increased dietary ramie ($P < 0.05$). The contents of Cys, Tyr, Val, and Met quadratically responded ($P < 0.05$) to dietary ramie level, with the highest values being observed in the muscles of goats fed 35% dietary ramie. Although neither linear nor quadratic effects were observed for Asp, Ser, Pro, Thr, Ile, Leu, Phe, EAA or limited amino acid contents, we detected significant differences among the 4 treatments ($P < 0.05$), with the highest values being observed at 35% ramie.

3.4. Fatty acid proportions

With the exception of C17:1 and C18:2 trans, an increasing proportion of ramie in the diet had no significant influence on the fatty acid composition of LD muscle (Table 5). Both C17:1 and C18:2 trans showed a quadratic response to increasing ramie proportion ($P < 0.05$); the highest C17:1 and lowest C18:2 trans ratios were observed at ramie content of 75% and 35%, respectively. The proportions of C12:0 (linear, $P = 0.099$), C18:3 n3 (linear, $P = 0.089$), C18:1 cis (quadratic, $P = 0.084$), and saturated fatty acids (SFA) (quadratic, $P = 0.070$) showed potential decreases with increasing proportion of dietary ramie.

4. Discussion

Carcass yield is an important aspect of feedstuff nutrient evaluation. In this regard, although we found that the daily gain in goats decreased significantly when the dietary content of ramie exceeded 75% (Tang et al., 2019), there was no significant difference in carcass weight or dressing percentage of goats fed diets in which up to 100% of alfalfa had been replaced with ramie. This is consistent with findings obtained for Boer goats, in which the dressing percentage remained unchanged when the proportion of dietary ramie was increased from 0 to 40% (Wei et al., 2019). The carcass yield of Xiangcun Black finishing pigs has been observed to numerically increase from 72.6% to 74.6% as the dietary ramie leaf powder levels increased from 3% to 12% (Li et al., 2018a). Contrastingly, in growing rabbits, a diet comprising 15% ramie was found to promote a greater

Table 2
Least square means of the carcass characteristics of goats fed dietary ramie as a substitute for alfalfa.

Item [1]	Alfalfa:Ramie				SEM [2]	*P*-value [3]		
	100:0	65:35	25:75	0:100		D	L	Q
DM intake, g/d	641	687	665	594	37.9	0.167	0.104	0.106
Initial weight, kg	21.9	21.9	21.9	20.9	0.91	0.986	0.454	0.627
Final body weight, kg	24.7	24.6	24.5	22.5	1.04	0.691	0.321	0.498
Daily gain, g/d	72.4	67.9	64.8	36.5	4.88	0.003	0.0001	0.0003
Feed conversion rate	7.11	10.97	10.6	12.1	3.73	0.772	0.365	0.748
Carcass weight, kg	9.98	9.88	10.07	9.29	0.631	0.816	0.518	0.591
Dressing percentage, %	40.0	39.7	41.2	40.3	1.39	0.863	0.671	0.885
Loin-eye area, cm^2	6.75	7.03	6.77	7.16	0.975	0.988	0.828	0.963

[1] The data for the DM intake, initial weight, final body weight, and daily gain of goats fed different diets were taken from Tang et al. (2019).
[2] SEM denotes the pooled standard errors of the means of a diet.
[3] D denotes the effects of diet; L denotes the linear response of ramie; Q denotes the quadratic response of ramie.

Table 3
Least square means of the meat quality of goats fed dietary ramie as a substitute for alfalfa.

Item	Muscle	Alfalfa:Ramie [1]				Average	SEM [2]	*P*-value [3]				
		100:0	65:35	25:75	0:100			D	L	Q	M	D × M
Moisture, %	LD	75.0	77.3	74.8	73.5	75.2	1.29	0.225	0.183	0.132	0.624	0.594
	VL	75.9	75.1	76.3	75.3	75.7						
	GM	74.9	76.4	74.3	74.0	74.9						
	Average	75.3	76.3	75.2	74.2							
Crude Protein, % DM	LD	85.4	86.8	83.1	82.9	84.5	0.94	0.0002	<0.0001	0.435	0.301	0.827
	VL	86.5	86.3	84.6	84.6	85.6						
	GM	86.5	85.9	84.3	83.5	85.0						
	Average	86.1^{a}	86.3^{a}	84.0^{b}	83.7^{b}							
Fat, % DM	LD	8.21	7.13	10.33	6.24	7.98^{a}	1.034	0.006	0.241	0.073	0.003	0.867
	VL	7.08	6.01	7.06	5.32	6.37^{b}						
	GM	6.09	5.28	6.92	4.71	5.75^{b}						
	Average	7.13^{ab}	6.14^{b}	8.10^{a}	5.42^{b}							
Ash, % DM	LD	4.77	5.19	4.68	4.60	4.81^{b}	0.14	<0.0001	0.009	0.006	<0.0001	0.996
	VL	4.99	5.31	4.84	4.78	4.98^{b}						
	GM	5.15	5.66	5.16	5.05	5.25^{a}						
	Average	4.97^{b}	5.39^{a}	4.90^{b}	4.81^{b}							
*L** at 24 h	LD	51.7	50.5	50.2	49.2	50.4	1.54	0.085	0.037	0.368	0.479	0.977
	VL	52.3	51.0	52.6	49.1	51.3						
	GM	51.0	50.2	51.3	47.7	50.0						
	Average	51.6	50.5	51.4	48.7							
*a** at 24 h	LD	20.4	23.0	22.9	21.1	21.9	1.28	0.140	0.565	0.116	0.209	0.959
	VL	20.6	20.8	21.1	19.1	20.4						
	GM	20.5	21.6	21.6	19.1	20.7						
	Average	20.5	21.8	21.8	19.8							
*b** at 24 h	LD	9.36	9.28	8.44	8.63	8.93^{a}	0.567	0.009	0.003	0.461	0.0001	0.697
	VL	7.81	8.02	7.69	5.89	7.35^{b}						
	GM	8.73	9.04	8.57	7.49	8.46^{ab}						
	Average	8.63^{ab}	8.78^{a}	8.23^{ab}	7.34^{b}							
pH at 45 min	LD	6.56	6.55	6.42	6.43	6.49^{b}	0.088	0.038	0.028	0.137	<0.0001	0.599
	VL	6.84	6.64	6.75	6.68	6.73^{a}						
	GM	6.62	6.31	6.42	6.40	6.44^{b}						
	Average	6.68^{a}	6.50^{b}	6.53^{ab}	6.50^{b}							
pH at 24 h	LD	5.63	5.62	5.67	5.69	5.65	0.035	0.235	0.118	0.182	0.112	0.888
	VL	5.66	5.66	5.64	5.72	5.67						
	GM	5.64	5.60	5.60	5.65	5.62						
	Average	5.64	5.63	5.64	5.69							
Drip loss at 24 h, %	LD	5.61	5.69	5.16	5.57	5.51	0.715	0.517	0.233	0.478	0.272	0.953
	VL	5.82	5.37	4.64	4.46	5.07						
	GM	5.16	4.50	4.32	4.93	4.73						
	Average	5.53	5.19	4.70	4.99							

LD = *longissimus dorsi*; VL = *vastus lateralis*; GM = *gluteus medius*; *L** = lightness; *a** = redness; *b** = yellowness.
[1] Within a row, means without a common superscript differ ($P < 0.05$).
[2] SEM denotes the pooled standard errors of the means of diet × muscle.
[3] D denotes the effects of diet; L denotes the linear response of ramie; Q denotes the quadratic response of ramie; M denotes the effects of muscle; D × M indicate the interactive effects between diet and muscle.

carcass yield (52.0%) compared with the 49.5% yield of animals fed a diet containing 7.5% ramie plus 7.5% alfalfa (Toledo et al., 2008). Although the dressing percentage or carcass yield (%) varied among goats, pigs, and rabbits following the inclusion of ramie in their diet, the carcass weight declined by more than 5.0% in goats, and by 1.76% to 4.53% in pigs and rabbits as ramie levels in the diet reached 25%, 9% and 7.5%, respectively. This indicates that the carcass weight will decrease as dietary ramie level exceeds the optimal levels by a certain percentage. Excessive fat powder may influence nutrient digestion and thereby affect growth performance and

Table 4
Least square means of amino acid concentrations (mg/g muscle DM) in the *longissimus dorsi* of goats.

Amino acids	Alfalfa:Ramie [1]				SEM [2]	*P*-value [3]		
	100:0	65:35	25:75	0:100		D	L	Q
Asp	78.9^{ab}	82.8^{a}	74.8^{b}	77.7^{ab}	1.83	0.029	0.148	0.634
Ser	30.3^{ab}	31.2^{a}	28.6^{b}	29.2^{ab}	0.67	0.037	0.057	0.673
Glu	131^{ab}	136^{a}	122^{b}	126^{ab}	2.9	0.012	0.029	0.771
Ala	44.9^{ab}	49.4^{a}	42.1^{b}	42.3^{b}	1.45	0.004	0.028	0.088
Cys	10.6^{b}	16.5^{a}	9.30^{b}	9.60^{b}	1.18	0.001	0.062	0.012
Gly	36.2^{ab}	37.5^{a}	33.6^{b}	33.5^{b}	0.87	0.006	0.005	0.324
Tyr	17.2	16.5	15.7	17.0	0.45	0.095	0.416	0.039
Pro	25.6^{ab}	27.1^{a}	24.4^{b}	25.2^{ab}	0.65	0.056	0.202	0.467
Arg	48.0^{ab}	49.9^{a}	44.2^{c}	45.7^{bc}	0.99	0.002	0.007	0.640
Thr	40.0^{ab}	41.8^{a}	37.9^{b}	39.2^{ab}	0.85	0.024	0.107	0.585
Val	39.8^{b}	45.9^{a}	37.7^{b}	38.6^{b}	1.32	0.001	0.054	0.032
Met	17.3^{b}	21.0^{a}	16.0^{b}	16.2^{b}	0.69	<0.0001	0.013	0.007
Ile	36.9^{ab}	38.8^{a}	34.8^{b}	36.3^{ab}	0.74	0.005	0.077	0.646
Leu	58.6^{ab}	60.2^{a}	55.2^{b}	57.2^{ab}	1.07	0.015	0.056	0.980
Phe	28.5^{ab}	29.3^{a}	26.9^{b}	28.2^{ab}	0.59	0.047	0.200	0.788
Lys	70.2	73.5	67.8	69.4	1.86	0.172	0.321	0.571
His	25.4	28.2	26.9	28.5	1.10	0.185	0.109	0.572
EAA	365^{ab}	389^{a}	347^{b}	359^{ab}	8.0	0.008	0.113	0.336
NEAA	375^{ab}	397^{a}	346^{c}	361^{bc}	7.9	0.001	0.012	0.455
EAA:NEAA	0.973	0.978	0.992	0.997	0.0071	0.078	0.012	0.970
TAA	740^{ab}	786^{a}	697^{c}	720^{bc}	16.1	0.004	0.045	0.336
LAA	87.5^{ab}	94.5^{a}	83.8^{b}	85.7^{ab}	2.31	0.014	0.119	0.194
BCAA	135^{b}	145^{a}	128^{c}	132^{bc}	2.9	0.002	0.040	0.246
FAA	238^{ab}	246^{a}	222^{b}	229^{ab}	4.8	0.006	0.021	0.779
DAA	357^{ab}	372^{a}	333^{b}	343^{b}	7.6	0.005	0.020	0.541

EAA = essential amino acids (sum of Lys, Try, Phe, Met, Thr, Ile, Leu and Val); NEAA = non-essential amino acid (sum of Asp, Ser, Glu, Gly, Ala, Cys, Tyr and Pro); TAA = total amino acids; LAA = limited amino acids (sum of Lys and Met); BCAA = branched-chain amino acids (sum of Val, Ile and Leu); FAA = functional amino acids (sum of Glu, Leu and Arg); DAA = flavor amino acids (sum of Asp, Glu, Gly, Ala, Arg and Tyr); EAA:NEAA = ratio of essential amino acids to non-essential amino acids.

[1] Column data marked with different superscript letters are significantly different ($P < 0.05$).

[2] SEM denotes the pooled standard errors of the means of diet.

[3] D denotes the effects of diet; L denotes the linear response of ramie; Q denotes the quadratic response of ramie.

carcass yield of animals. Although the fat powder in the 4 diets of the present study increased from 8% to 15%, nutrient digestibility was similar between the diets when 0 (15% fat powder) and 35% (8% fat powder) of alfalfa was replaced by ramie, whereas it differed between the diets in which 0 (15% fat powder) and 100% (15% fat powder) of alfalfa was substituted with ramie (Tang et al., 2019). This implies that the difference in diet nutrient digestibility among the 4 treatments was mainly caused by the ramie proportion rather than by the amount of fat powder. Therefore, decreased nutrient digestibility may be responsible for the decline in carcass weight.

The findings of the present study indicate that replacing alfalfa with a low proportion of ramie does not negatively affect carcass traits in goats. Generally, the loin-eye area is positively related to the meat yield performance of livestock. Li et al. (2018a) found that increasing dietary ramie leaf powder significantly increased the loin-eye area in pigs and attributed it to the high fiber content of ramie. These results are in contrast with our observations in goats, in which the loin-eye area was not significantly influenced by increasing proportion of the dietary ramie. The fiber content in diets used in both studies was similar, suggesting that the differences in animal species may have been the factor that contributed to these inconsistent observations. A few studies have evaluated the effects of increasing dietary ramie proportion on loin-eye area of ruminants, and more work is needed to verify these effects.

From the perspective of meat production, the crude protein and moisture content of muscles are the most important characteristics. In pigs, increasing the proportion of ramie leaf powder in the diet quadratically reduces the DM and increases the crude protein content of the *longissimus thoracis*, with ramie leaf powder inclusion at 12% resulting in the lowest measured DM and crude protein content (Li et al., 2018a). At the same level of ramie inclusion, the DM content of the *biceps femoris* muscle was not influenced, whereas the crude protein content was decreased significantly (Li et al., 2018a). In the present study, although the inclusion of ramie in the diet had no significant influence on muscle moisture content, higher proportions of dietary ramie were associated with a decrease in muscle crude protein, which is partially consistent with findings in pigs (Li et al., 2018a). In a previous study on goats, the *longissimus* muscle was found to contain 79.5% to 85.1% crude protein when the diet included 36% ramie residues with or without bast fiber (Zhang et al., 2019). These observations thus suggest that inclusion of a high proportion of dietary ramie will reduce the muscle protein content in goats. A previous study showed that 100% of alfalfa replacement with ramie upregulates mRNA expression of the apoptotic genes B-cell lymphoma extra-large (*Bcl-xl*) and Bcl-2-associated X protein (*Bax*) in rumen and *p53* in jejunum, which leads to gastrointestinal tract tissue damage (Liu, 2018) and restrains nutrient absorption. Furthermore, ramie inclusion in the diet decreases the production of ammonia nitrogen; low ammonia nitrogen concentrations (6.18 and 4.12 mg/dL) were observed in treatments with 65% and 100% substitution of ramie for alfalfa, respectively (Tang et al., 2019). Based on numerous reports, the optimal level of ruminal ammonia concentration for microbial protein synthesis is 8.4 to 29.4 mg/dL (McDonald et al., 2002), and 1 to 2 mg/dL of ammonia was adequate to synthesize microbial crude protein (Clark et al., 1992). Ammonia decline resulting from ramie inclusion may decrease the synthesis of microbial crude protein, which thereafter reduces the synthesis of proteins in muscle.

Although the color of muscle is only weakly correlated with meat flavor, it does, nonetheless, strongly influence consumer preference (Zhang et al., 2015). We observed that values of the meat color indices L^* and b^* decreased with an increase in the proportion of dietary ramie, which contrasts with the findings of previous studies (Li et al., 2018a), in which it was found that increasing the dietary contents of ramie leaf powder had no appreciable effects on the color of pig meat. Meat color depends not only on the quantity of myoglobin, but also on the relative proportions of the 3 main states of myoglobin on meat surface. Ledward (1985) suggested that the rate of metmyoglobin formation at the muscle surface, which greatly correlated to the color quality of muscle, is dependent on the oxygen consumption rate and the activity of an enzymatic reducing system; this reducing system is influenced by the time and pH history of the muscle. We also found that the color value of b^* at 24 h was negatively related to the pH value at 45 min (data not shown). Thereby, pH history and the metmyoglobin formation rate on the muscle surface may explain the difference in the color quality among 4 treatments and among 3 kinds of muscle. More studies should be carried out on the molecular mechanism of ramie affecting the formation of meat color.

The ultimate pH of muscles is a major trait used in meat quality determination and is related to the degradation of glycogen and the release of lactate during the pre- and post–slaughter periods (Wei et al., 2019). We found that although muscle pH at 45 min after slaughter was affected by dietary ramie levels, the ultimate pH at 24 h after slaughter was similar across treatments and consistent with previously reported values (Li et al., 2018a; Zhang et al., 2019). These findings therefore tend to indicate that muscle quality is not substantially affected by ramie inclusion.

Essential amino acids are those considered necessary to meet human requirements, whereas DAA affect meat flavor. The LD muscle in goats fed a 35% ramie replacement diet had the highest

Table 5
Least square means of fatty acid proportion (g/100g of total fatty acid methyl esters) in the *longissimus dorsi* of goats.

Item	Alfalfa: Ramie [1]				SEM [2]	*P*-value [3]		
	100:0	65:35	25:75	0:100		D	L	Q
C12:0	0.0400	0.0442	0.0383	0.0296	0.00471	0.204	0.098	0.176
C14:0	1.10	1.17	1.21	0.98	0.116	0.559	0.591	0.238
C14:1	0.0583	0.0867	0.0833	0.1013	0.0192	0.458	0.152	0.797
C15:0	0.270	0.302	0.282	0.273	0.0279	0.848	0.941	0.454
C15:1	0.153	0.205	0.061	0.123	0.0416	0.141	0.245	0.964
C16:0	19.2	18.3	18.5	18.1	0.50	0.408	0.167	0.666
C16:1	1.75	1.95	1.93	1.68	0.137	0.429	0.759	0.115
C17:0	1.10	1.19	1.21	1.26	0.069	0.426	0.117	0.790
C17:1	0.677	0.760	0.860	0.724	0.053	0.092	0.245	0.044
C18:0	18.4	19.0	17.8	17.6	1.17	0.820	0.466	0.718
C18:1 trans	1.46	1.64	1.85	1.74	0.274	0.652	0.279	0.602
C18:1 cis	45.5	46.8	47.7	43.8	1.41	0.241	0.561	0.083
C18:2 trans	0.178	0.130	0.143	0.169	0.0146	0.140	0.770	0.026
C18:2 cis	5.63	5.85	6.86	6.16	0.628	0.468	0.315	0.496
C18:3 n3	0.488	0.393	0.403	0.372	0.0594	0.257	0.088	0.522
C20:2	0.0500	0.0692	0.0542	0.1421	0.0440	0.664	0.422	0.609
C22:0	0.273	0.367	0.267	0.266	0.0412	0.266	0.513	0.222
C22:1	3.42	4.25	2.64	4.49	0.498	0.083	0.514	0.381
C20:5	0.328	0.317	0.310	0.455	0.0789	0.568	0.336	0.338
SFA	40.4	37.7	36.8	39.2	1.34	0.259	0.423	0.070
MUFA	52.9	55.1	54.3	52.5	1.51	0.565	0.803	0.179
PUFA	6.66	6.67	7.77	7.21	0.661	0.534	0.317	0.718
PUFA:SFA	0.165	0.177	0.213	0.184	0.0215	0.366	0.290	0.367

SFA = saturated fatty acids (sum of C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C22:0); MUFA = monounsaturated fatty acids (sum of C14:1, C15:1, C16:1, C17:1, C18:1, C22:1); PUFA = polyunsaturated fatty acids (sum of C18:2, C18:3, C20:2, C20:5); PUFA:SFA = ratio of polyunsaturated fatty acids to saturated fatty acids.
[1] Within a row, means without a common superscript differ ($P < 0.05$).
[2] SEM denotes the pooled standard errors of the means of diet.
[3] D denotes the effects of diet; L denotes the linear response of ramie; Q denotes the quadratic response of ramie.

essential amino acid and total amino acid contents, implying that goat meat with a higher nutritive value could be produced by establishing a dietary regimen in which 35% of dietary alfalfa is replaced with ramie. Furthermore, the muscle content of almost all the individual amino acids in the 35% group was the highest among those recorded in the 4 treatments, particularly with respect to Cys, Val, and Met. This contrasts with the findings in Boer goats, in which the contents of most individual amino acids, TAA, and DAA in the LD muscle were unaffected by ramie inclusion (Wei et al., 2019). Given that higher amino acid contents in the meat of Yun-ling Black goats is associated with less drip loss and greater juiciness and flavor (Jia et al., 2007, 2009), we speculate that the juiciness and flavor of goat meat could be improved by feeding diets in which 35% of dietary alfalfa is replaced with ramie.

Given that the ratios of polyunsaturated fatty acids (PUFA) to SFA and unsaturated fatty acids are important with respect to human health, the amount of carcass fat deposited in muscle tissues ideally needs to be considered. In the present study, we found that the fatty acid profile of LD muscle was unchanged by the dietary inclusion of ramie, and only numerical increases in the proportions of stearic acid, linoleic acid, PUFA, and the PUFA-to-saturated fatty acid ratio were observed when 35% of alfalfa was replaced with ramie. These proportions were significantly increased in Boer goats (Wei et al., 2019) when ramie was included at 20%, and in Xiangcun Black finishing pigs (Li et al., 2018b) when ramie leaf powder was included at 6%. The proportions of individual fatty acids in the LD muscle of Liuyang Black goats are not appreciably influenced by the type of ramie (either raw or hay) included in the feed (Zhang et al., 2019). Stearic acid and PUFA are functional nutrients of meat that can contribute to flavor enhancement (Brennand and Lindsay, 1992), reduce the risk of cardiovascular disorders in humans, and decrease human blood plasma cholesterol concentrations (Kadim et al., 2003). However, the optimal proportion of ramie in the diets of goats with respect to enhancing the contents of these functional nutrients will require further study.

5. Conclusions

Our results indicate that diets in which up to 35% of alfalfa is replaced with ramie, corresponding to a content of 126 g/kg DM ramie, is suitable for goats. This diet was found to improve the crude protein content and amino acid composition of goat meat. On the basis of our findings, we propose that ramie, as a partial replacement for alfalfa, could be utilized as a potential forage source in the diets of goats.

Author contributions

Conceptualization, Shaoxun Tang, Yao He, and Hongrong Wang; Conceptualization; Investigation: Yao He, Peihua Zhang, Jinhe Kang, and Jinzhen Jiao; Software: Qiongxian Yan; Methodology, Duanqin Wu; Formal Analysis, Yao He, Shaoxun Tang; Data curation, Xuefeng Han, Lihuai Yu; Resources: Duanqin Wu; Writing - Original Draft Preparation, Shaoxun Tang; Writing – Review & Editing, Zhiliang Tan; Supervision, Zhiliang Tan; Project Administration, Hongrong Wang, Chuanshe Zhou; Funding Acquisition, Zhiliang Tan, Duanqin Wu.

Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, and there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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